Interreg IV A
Oberrhein / Rhin supérieur

„Der Oberrhein wächst zusammen – mit jedem Projekt.“
„Dépasser les frontières: projet après projet“
„Transcending borders with every project“

Geopotenziale des tieferen Untergrundes im Oberrheingraben

Potentiel géologique profond du Fossé rhénan supérieur

Geopotentials of the deep Upper Rhine Graben

Proceedings
of the technical workshop
on 18.11.2010 in Freiburg

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The technical workshop of the Interreg IV A project "Geopotentials of the deep Upper Rhine Graben (GeORG)" is aimed at presenting first scientific results and at discussing the project with the general public as well as with scientific experts. In the first session "Communication" the objectives, contents, potential uses and the broader context of GeORG is presented. The session "Positioning" focuses on the applied techniques for a transnational harmonization, interpretation and modeling of geological data in GeORG and on the scientific exchange with thematically related projects of geological modeling for the use of geopotentials.

These proceeding are a collection of the abstracts submitted to the technical workshop held on the 18th of November 2010 in Freiburg.

Content

Why an Interreg project GeORG

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In the Upper Rhine Graben, soil and subsurface areas are intensively used in the domains of agriculture, groundwater management, exploration of natural resources and, increasingly for geothermal energy. Therefore, these study areas have been subjects of geoscientific interest for many years. Serious information on properties of the deep subsurface and the processes taking place therein are an essential condition for a sustainable utilisation and also for appropriate considerations in case of competing types of use. Neither geology nor phreatic zones stop at frontiers. For this reason, in the Upper Rhine Region, these geoscientific questions are treated across national boundaries. The European Union assists this co-operation within the limits of its cohesion policies.

However, since a couple of years, the deep subsurface in the Upper Rhine Region is more and more in use. Questions concerning potential use have been increasingly coming to the fore over the last years. Traditionally, hydrocarbons are exploited in some parts of the Upper Rhine Graben. The use of drinking and mineral water has also a tradition that goes back to the Romans. Discussion about climate protection has accelerated the considering of aspects of geothermal use of the deep subsurface, but also of Carbon Dioxide Capture and Storage (CCS) as well as the storage of compressed air. Our current knowledge about natural earthquakes in the Upper Rhine Region, but also about the results of artificially initiated earthquakes in some sites has shown that the use of geo-potentials must also consider geological risks.

The geological surveys and the other project partners in Germany, France, and Switzerland have a long tradition of successful co-operation. All participants of today's workshop have achieved a reputation of competent and reliable project partners of the European Union and the INTERREG authority.

Experiences from border-crossing projects of previous INTERREG programs showed us the advantage of geological studies and data that had been developed and co-ordinated across national boundaries, and which concerned not only experts and administration but also political decision makers. For studies of the deep subsurface, the geological boundaries of the Upper Rhine Graben display the natural, homogenous areas, which have to be investigated in common. Meanwhile, the political discussion about competing land use and management also concerns the deep subsurface.

The geological surveys in the Upper Rhine Region can revert to a common history of geological investigations and research concerning the deep subsurface as well. The first border crossing project was already developed in the 1970s and was also financed by European funds. Since that time, data acquisition and interpretation have been continuing both individually and with respect to different requirements in the different countries. But within the last three decades, geoscientific working methods have also been considerably modernized. For this reason, "bringing together contributions from each single country and developing them in common" has been chosen as a keynote for the GeORG Project. Depending on their particular skills, the respective partners assume the general management for specific tasks during the whole running time of the project. Such a grouping of individual strengths engenders added value for the project. Competences are transferred to the partners, which mean better qualifications for all persons in charge. Bringing together the best from the co-operating countries to resolve problems better together is an essential part of the philosophy of the tripartite European metropolitan region of the Upper Rhine.

The objectives with regards to content of GeORG are the following: the compilation, harmonisation, and documentation of existing data in a transnational database; the development of a three dimensional, computer-generated, geological model for the important geological units based on boreholes and new processed seismic data; the parameterisation of geological bodies with the help of specific values of rocks and ground water; a general derivation scheme for future planning and specific projects; and finally, the public availability of the project's results in a modern form.

The main results of the project are generated as electronic geological data. For this reason, the project also covers another focus of the cohesion policies in the European Union, that is the development of a common infrastructure for geological data (EU directive 2007/2 INSPIRE). Once completed and conforming to the intention and directives of the European Union, the results of this transnational compilation will be available as specific geological data for the public. It would be impossible to gather more “Geo” and more “Europe” together.

An important intention of the INTEREG programs is to initiate projects in order to establish long term partnerships, but also the development of an infrastructure which will be autonomous at the end of the project. Conditions, conception and previous results match perfectly well in the project setting mentioned above. At the end of the project, we will present an outlook on possible potentials for future development.

The ambition and the intention of today’s workshop is a presentation of the first and preliminary results, but also the communication of the current results to the public and to those who grant subsidies, as well as being a professional exchange between experts in a larger context. I would like to express already today my gratitude to the INTERREG program its financing and to all the project partners for their excellent co-operation.

Geopotentials of the Upper Rhine Graben

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The Upper Rhine Graben with its geological history is well stocked with numerous different geopotentials. The ongoing discussion on climate change has especially lead to increasing interest by professionals and by the general public.
A sustainable and efficient use of natural resources requires a good knowledge of the deep subsurface. In the context of the GeORG project, new data und innovative technical possibilities have allowed the existing geothermic inventory established in 1979 and 1981 to be developed. An important part of the project consists in harmonizing data sets across national boundaries and in compiling a laminar 3D model of the geological subsurface.
The project provides additional information on geological settings for the use of deep geothermal energy production, on the depth of the aquifers (mineral or thermal water) and also on a possible CO2 sequestration or compressed air storage.
Furthermore, the first indications of possible conflicts stemming from using geopotentials can be pointed out.
The data compiled in the GeORG project provides basic information for the planning of new projects but cannot replace detailed planning principles.

Importance of deep geothermal energy within the political strategy in the canton of Basel-Country

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(Deep) geothermal energy is one of the hope-bearers regarding energy policy in the canton of Basel-Country.

Energy policy has a long tradition in Basel-Country.

As one of the first cantons, Basel-Country concluded its own cantonal energy law already in 1991. Since then, the canton strongly emphasizes an efficient, economic and environmentally friendly use of energy and a substition of non-renewable with renewable energy sources, as far as possibe. Within this context, the canton offers an energy development programme since 20 years and has an active impact on the developments of buildings.

With its energy strategy in 2008, the government has continued with this long-year tradition

Following the publication of the most recent reports of the Intergovernmental Panel on Climate Change (IPCC), approx. fifty approaches regarding different aspects of energy policy have been submitted to the parliament of the canton of Basel-Country. With its strategy for energy policy in the canton of Basel-Country from the 8th of April 2008, the government has acted on these requests and set the way of energy policy for the next years. The strategy is aimed at the 2000-Watt-society and contains 10 principles as well as 27 concrete activities to adopt the approaches.

The energy strategy of the canton of Basel-Country emphasizes efficiency and the use of renewable energy sources.

The potentials of renewable energy sources in the canton of Basel-Country are limited. Besides, conflicts of interests exists (e.g. between wind energy and landscape protection or between hydroelectric power and fishing industries or ecological interests). Almost each concrete project encounters resistance. Already by now it becomes foreseeable that only a fractional amount of the theoretically available potentials can be utilized. Therefore, the energy strategy focuses primarily on efficiency and on a well-balanced mix of various renewable energy sources.

The voting population has recently decided about measurable goals in the energy policy.

On the 26th of September 2010 the voting population of the canton of Basel-Country has decided about measurable goals in the energy policy regarding the thermal heat requirements for old and new buildings and in terms of the proportion of renewable energies. According to these changes of the cantonal energy law becoming effective on the 1st of January 2011, the amount of renewable energies is scheduled to increase to 40 percent of the total energy consumption (mobility excluded) by the year 2030.

Geothermal energy has been promoted in the canton of Basel-Country for a long time and the promotion continues.

For a long time, the canton of Basel-Country has funded the use of shallow geothermal energy production. Up to now, already several hundreds of plants with two geothermal probes at an average have been realized within the canton. This support of near-surface geothermal energy is continued on the basis of the energy strategy mentioned above (activity No. 21 of the energy strategy). Due to its high long-term potential, deep geothermal energy is still implemented in the energy strategy as an option for the future - despite the throwbacks that occurred in the Basel project (activity No. 22).

Geothermal energy is the energy source for the future and the hope-bearer in terms of energy policy.

According to various studies for Switzerland, the enormous long-term geothermal potential that is theoretically accessible is predicted to be the largest of the renewable energy sources. The geothermal energy is considered to be free of CO_2 emission and correspondingly clean. It is hardly associated with adverse effects on landscape. Geothermal energy production is expected to produce low costs compared with renewable energy sources and to make a substantial contribution to the energy supply in Switzerland. From today's point of view, geothermal energy will probably stay the only technology for a longer time which is capable to contribute substantially to the cover of base load and to produce base energy on a grand scale regardless of weather conditions. In this respect, (deep) geothermal energy is the energy source for the future and a hope-bearer in terms of energy policy.

Further research of geothermal energy is important and the project GeORG is one piece of the puzzle.

The project for the usage of deep geothermal energy in Basel showed that the use of big sub-surface energy resources is far from being secured. The technology is still in its initial stage and the knowledge of the subsurface is still limited. Apart from legal, administrative and financial barriers, especially geological information on a regional and local scale is a prerequesite for the identification, development and sustainable management of suitable sites. In this respect, further research of geothermal energy and the combination of existing knowledge of the subsurface is very important within this context. The project GeORG takes off exactly from this point and provides the basis for possible feasibility studies within the next years. From the view of the canton of Basel-Country, GeORG is therefore an important piece of the puzzle.

The project „Speicherkataster"– Geological data in Baden-Württemberg

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Introduction

Within the project "Information system for reservoir rocks in Germany as a base for environmentally friendly geotechnical and energy uses of the deep subsurface (Speicher-Kataster Deutschland)" which is co-ordinated by the Federal Institute for Geosciences and Natural Resources, the State Geological Surveys in Germany compile maps based on nationwide harmonized data for the geological suitability of reservoir and confining rocks. These storage complexes are defined as lateral delimitable units in the same sedimentary depositional environment. Such complexes must show geological horizons suitable for storage. The project's intention was the recognition of potential reservoir areas for the underground storage of gas in saline aqui-fers.

Reservoir rocks are primary porous rocks, but also secondary fissured and/or cavernous rocks (fissure/karst conduits). Confining rocks are siltstones or evaporates with poor overall permeability.

In the State of Baden-Württemberg, the large sedimentary basins of the prealpine foreland (Molasse basin) and the Upper Rhine Graben are particularly interesting. But these two regions show a significant difference in their geological and tectonic development as well as in the lithology of the rocks.

Basics

In Germany, based on specific criteria (depth of the storage complex and minimum thickness), a systematic and nationwide uniform compilation and delimitation of regions suitable for storage due to their reservoir and confining properties was established by the State Geological Surveys.

Because of the multitude of different storage complexes in both regions, only existing and available informa-tion could be treated: i.e. drillings, bedding and isopach maps, but also different data pools concerning hydro-chemistry, hydraulics, and rocks properties.

Results

Potential maps on the scale of 1: 1.000.000 have been compiled for complexes defined according to criteria mentioned above. Furthermore, detailed cartographic representations regarding extension, thickness and geological position in the deep subsurface of potentially appropriate storage complexes have been worked out on the scale of 1:300.000.

The mapping method applied and the interpreted data allow an initial synoptic representation of the storage potential of the rocks in the deep subsurface of both regions studied (Molasse basin and Upper Rhine Gra-ben). As a result, small-scale maps of regions have been compiled, where storage complexes satisfy basi-cally the standards set up concerning lithology, depth, and thickness, and which are qualified for further con-sideration.

Evaluation of the results is complicated because of the horizontal and vertical heterogeneity of the lithological structure of the complexes, an outlook concerning the stability of spatial proportions, and also because of the complex geological and tectonic setting of the region studied. This is particularly important for the Upper Rhine Graben and it strongly limits its qualifying potential for permanent storage. For more detailed analysis further studies are necessary. In the Upper Rhine Graben, the border-crossing and harmonized revision of the geology of the deep substructure as well as the generation of a 3D model of the geological underground all serve as the basis for ongoing investigations. These are currently being carried out in the context of the In-terreg project „Geopotenziale des tieferen Untergrundes im Oberrheingraben – GeORG" by French, Swiss and German partners and co-ordinated by the Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau.

Exploring deep subsurface: Techniques, workflow, data processing and status of the GeORG-project

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Introduction

The EU project GeORG (Geopotentials of the deep Upper Rhine Graben) is funded by the Interreg IV A Programme Upper Rhine from October 2008 to September 2011. The project aims at the construction of a transnational database allowing statements about deep subsurface geopotentials, e.g. geothermal energy, thermal and mineral waters, possibilities of CO2 sequestration and storage of compressed air. In the Swiss project area information about problems regarding induced seismicity are included.
The basis is a digital, three-dimensional geological model parameterized with hydrogeological and geothermal properties. The model area is shown in Fig. 1. The interior modeling zone has a N-S-extension of approx. 270 km and varies between 40 and 50 km in E-W-extension.

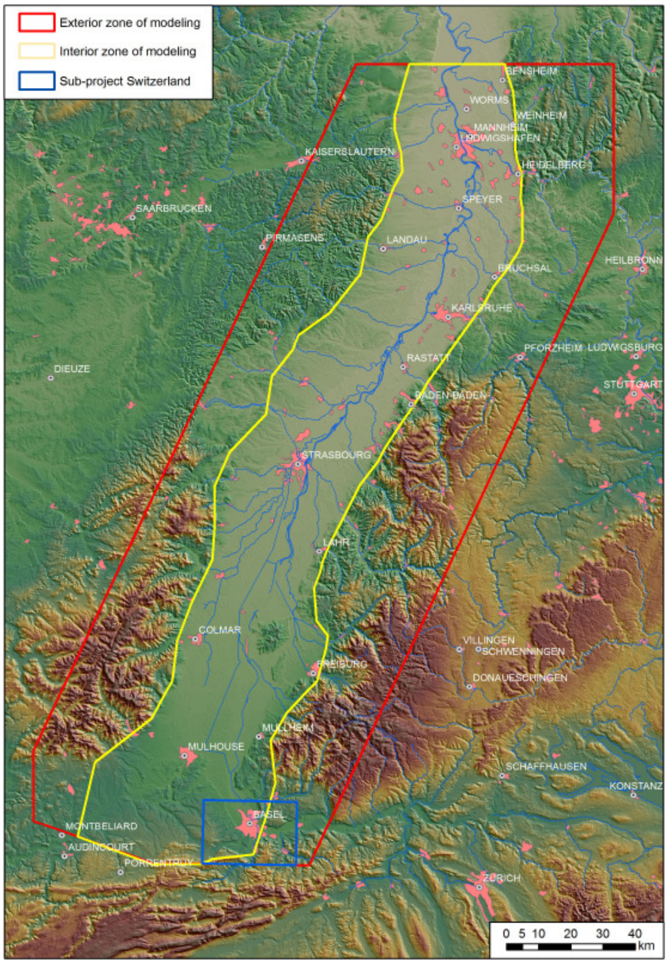

Fig 1: Modeling zones of the GeORG project.

The exterior project area is taken into consideration for further structural analysis without detailed modeling. The Upper Rhine Graben is a complex rift and wrench system. Rifting started in the Eocene and led to a Cenozoic graben fill of up to 3 km thickness that consists of an alternating succession of terrestrial and marine sediments. In the area of Mulhouse Potassium salt deposits of Paleogene age have partially been mobilized by diapirism forming salt walls.The Kaiserstuhl forms the biggest complex of the locally occuring volcanic rocks. The Cenozoic graben fill is underlain by Mesozoic and late Paleozoic rocks, which also may form important geopotential sources due the occurrence of sandstones and limestones with varying permeability. Variscan-deformed rocks represent the basement of the model.

The area is tectonically highly-deformed: Apart from normal faults with a vertical offset of > 1 km strike-slip structures with transtensive and transpressive elements are prominent features.The reproduction of the complex block tectonics combined with the development of a conclusive structural-genetic concept is one of the main challenges to the project.

Data basis and data harmonization

Within the project the following input data are used:

- 2150 drillings (lithological description, geophysical logs)
- 5400 km reflection seismic data (2D profiles, velocity models)
- hydrogeological and geothermal data sets
- results of previous works (structural maps, cross sections, 3D models of sub-areas)

The data basis mainly comes from the archives of the project partners. Further information, especially seismic profiles, have been provided by various oil companies. The data have multiple sources and various acquisiton dates, and their interpretations have gone through several paradigm changes. Therefore, it was necessary to standardize the data with regards to technical parameters and content prior to further analysis.

The geodata have been stored with different, country-specific coordinate systems and first had to be transformed into a consistent spatial reference system.
Hydrogeological and geothermal parameters have been stored in local databases with varying units of measurement, correction values and methods. In the course of the project, standardized values are made available to the project workers on a central platform.
Seismic profiles show different datum planes and have been processed with varying correction methods. A reprocessing on a consistent basis leads to a better comparability of the data and improves their quality (see BECCALETTO et al., this workshop).

Master file data of deep drillings (location of the kelly bushing, vertical deviation of well path) have been revised and corrected, if required. The lithostratigraphical description of drilled units varies with the date of drilling and the status of knowledge at that time, but also with different regions and partially with workers in charge, especially in Tertiary units.
Within the scope of the GeORG project representatives of the geological surveys of Baden-Wuerttemberg (LGRB), Rhineland-Palatinate (LGB) and France (BRGM) as well as of the University of Basle agreed on a consistent nomenclature for the stratigraphic Tertiary units of the Upper Rhine Graben within the project area (Fig. 2).
The suggestions of the sub-sommission Tertiary of the DSK published by then served as a starting point. They have been revised / completed with respect to the available and used well data and seismic profiles and have been adjusted to the stratigraphic systematics used by the regional state authorities. For the first time, a transnational, consistent differentiation of the 12 formations defined for the project has been carried out. It is based on the lithological characteristics of rock units documented in well reports and allows to derive conclusions on the thicknesses and distributions of geotechnically and hydrogeologically comparable rock bodies.

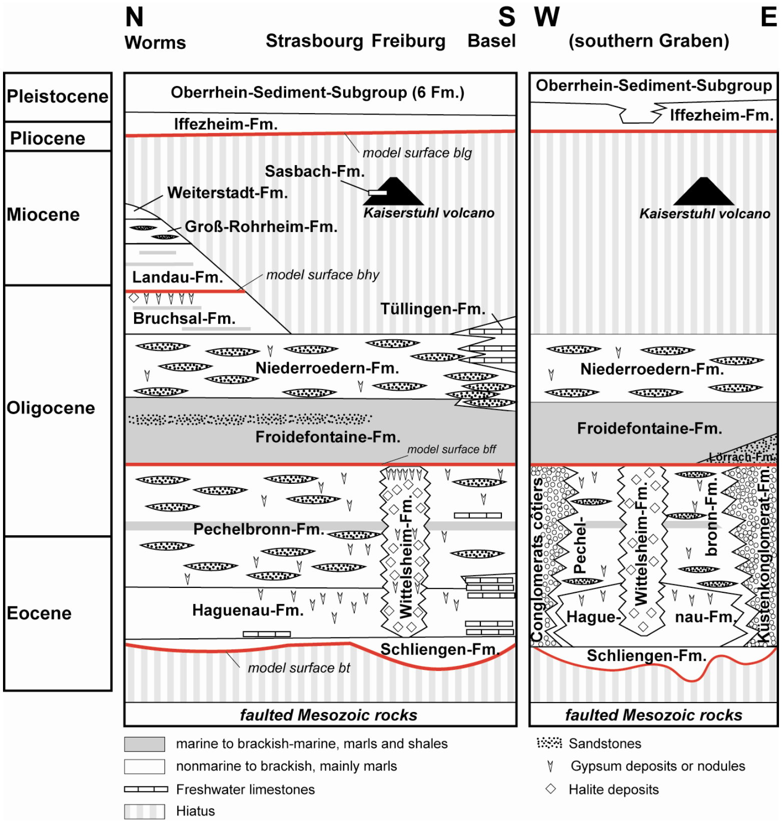

Fig. 2: Harmonized GeORG nomenclature of Tertiary sediments.

Seismic interpretation and 3D modeling

The seismic analysis (see BECCALETTO et al., this workshop) and 3D modeling is performed with the software packages SeisVision and Gocad. As the input data have been measured with different methods (drillings in meter below well location, seismics in travel time, older structural maps and models usually in m above sea level), building a velocity model is essential for combined display and analysis. The 3D model is first built in time domain and is subsequently converted into depth.

In the first part of the modeling surface objects like faults, bounding surfaces of geological units and hull surfaces for salt diapirs and volcanic rocks are generated (s. Fig. 3). The modeling of the structural inventory is especially complex and time-consuming. With regard to their strike direction, apparent dip and vertical offset, fault sticks detected on the seismic profiles are correlated to surfaces which are preferably free from twist effects. At the same time it is checked, if the fault surfaces constructed fit into the main structural concept. After that, focus is set on the modeling of a water-proof fault network.

Horizons which are well detectable in seismic profiles are modeled in time domain. If the resolution of horizons is low because of poor impedance contrasts or great depth, they are added subsequently into the depth-converted model by means of well markers and thickness distributions. This is especially applied for Mesozoic units.

After the modeling of surfaces all objects are transformed into a volume model. Due to the resolution and size of the area modeled, a division into sub-models with consistent boundaries is inevitable.

After that, volume bodies are parameterized with with hydrogeological and geothermal properties and focus is set on the derivation of geopotentials.

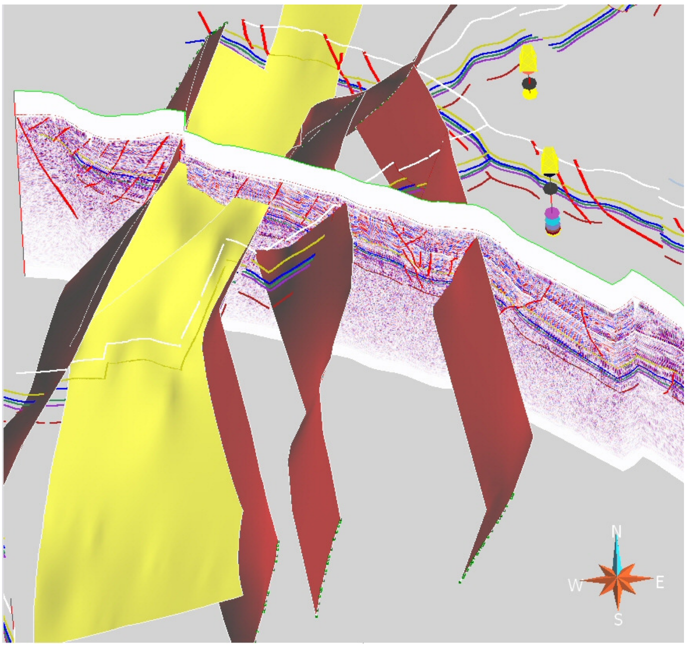

Fig. 3: Seismic profile with faults and horizons detected (coloured lines), fault surfaces (red), and horizons (yellow).

Products

Products in GeORG comprise maps, cross sections and 3D models of pilot areas in order to assess geopotentials and georisks. These include:

- Structural maps and cross sections
- Thickness distributions
- Facies distributions of selected geological units
- Temperatures at certain depths
- Informations about heat conductivities (pilot area Landau - Karlsrhe - Soultz)
- Distribution and depth of selected storage and barrier complexes for CO_2 sequestration and gas storage
- Seismic risks (sub-project Switzerland)
- Parameter sets of heat in place, hydrochemical properties, permeability and porosity of selected units

Current information in the internet at www.geopotenziale.org.

The GeORG project: seismic interpretation, structural pattern and 3D modeling of the Upper Rhine Graben - first scientific results

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The Upper Rhine Graben (URG) is an area with a great geological potential, in relation with many topical applications: deep geothermal energy, CO2 storage, hydrogeology, or seismic hazards. A detailed knowledge of the deep geological structure of the URG is needed to safely and successfully use this potential.
The final goal of the INTERREG IV European GeORG project is therefore to gather complementary data from the German, Swiss, and French partners, in order to build a 3D geological model of the URG; the latter will ultimately model the geometry of 17 selected geological markers, chosen between the Variscan basement and the surface.
The input data of this 3D Gocad model are mostly represented by the interpretation of about 5400 km of reprocessed seismic lines (3900 km in Germany and 1500 km in France), and the description of more than 1000 wells, both coming from the oil and mining industry. It's the first time that such an amount of subsurface data is gathered, studied and promote in the URG.

A significant part of our project consists therefore in the modern reprocessing of old seismic lines, acquired by the oil companies during the last decades. Indeed the interpreted seismic lines represent the basic frame of the 3D geological model. The use of modern processing methods, applied to old raw seismic data, significantly improves the quality of the resulting seismic section, leading to enhanced descriptions of the geological structures. Compared with old-processed line, the newly processed lines display a better (1) continuity and horizontal-vertical resolution of the seismic horizons or groups of horizons, (2) geometric characterization of faults and fault zones. We therefore aim to present and illustrate the processing sequence for the French and German lines, which were characterized by different initial seismic formats.

The scientific interests of this project are numerous, mainly regarding the structural frame of the URG. We aim to present the first results of our work, including new seismic interpretations and a first draft of the 3D model. We put the emphasis on the inventory of the various observed structural features (e.g. main border faults, normal and strike-slip faults, salt domes, southerly Jura thrust front), and their implication regarding the structural evolution the URG. We then focus on the predominant role of the Miocene-to-present NNE-SSW strike-slip regime in the present-day 3D geometry of the URG; this strike-slip regime, characterized by the development of transtensional faults and negative flower structures, tends to obliterate the morphology of previous normal faults related to the first rifting phases of the URG; they therefore give a distorted view of the pre-Miocene rift system. We also discuss the structural heritage of late Variscan faults at the origin of some of the present-day structures observed in the URG. We finally present a selection of 3D pictures of the above structural features.

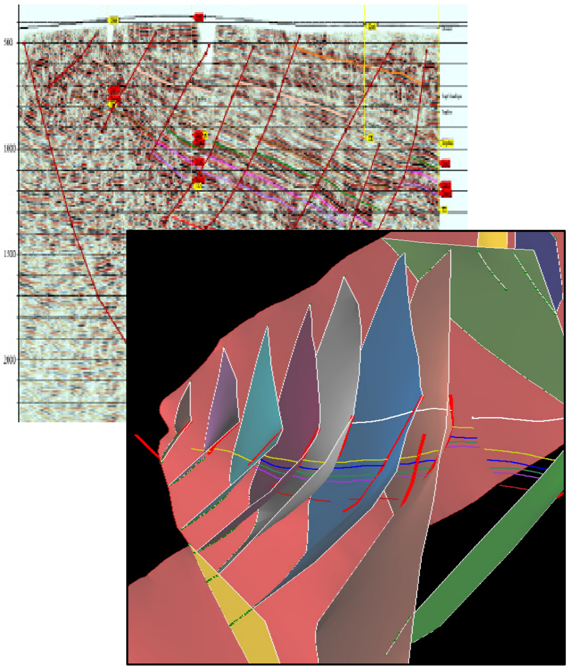

Fig. 1: Example of normal faults in 2D (seismic section) and 3D (Gocad modeling).

Geological 3D-model of the Basel region – a tool to explore geopotentials

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The growing interest for using geopotenials of the deeper underground such as geothermal energy, groundwater or the potential to store gases requires exploration, rules and planning concepts. “First come first serve” is actually not what should be envisaged.
Especially, in densely populated areas like Basel, subsurface information is required in many different fields. Beside the interest in geopotentials, groundwater resource management, clean-up operations of ancient polluted sites, construction of traffic lines and seismic hazard evaluation are the main issuses.
The present seismicity in Switzerland is moderate, but strong earthquakes have occurred during the last centuries. To mitigate the risk of earthquake damage in the Basel area, relevant geologic and seismologic information was integrated in a cooperation project of the Swiss Seismological survey (SED) and the Applied and Environmental Geology Group (AUG) to create a “Quantitative Microzonation Map” (2006) of the Basel area. The microzonation is based on a 3D geological model of the Basel area. The information of the microzonation can be used in the domain of civil engineering to evaluate the static aspects of building construction. The result is a public GIS product on the “Geoportal” of the Basel administration.
In future, a further development of the earthquake risk evaluation project is the calculation of real time shaking maps. After an earthquake shock such maps could improve the coordination of the emergency service. The calculation of such maps will require detailed information on the deep tectonic framework of the Basel area.

Generally, geological data are of low interests unless they are systematically organized in geological databases. Modern 3D geological modeling techniques are powerful tools that allow visualizing geological data thereby providing the relevant information for modern planning and resource management. These tools can be continuously developed and specified (scales and degree of resolution) according to the requirements of different questions. At the regional scale, a major effort for the development of such tools led to a transnational INTERREG application.
The main goals of the INTERREG IV project GeORG in the Basel region is the development of a comprehensive and flexible 3D model (Fig. 1). Thereby, the existing model of Basel (ZECHNER et al., 2001) are revised, refined and extended to an area of about 20 x 30 km in size and to a depth of about 6 km
This includes an integration of data from about 9000 boreholes, 15 reflection seismic lines, as well as high-resolution DEMs were imported. Beside the geological maps from France (1:50.000), Germany (1:25.000) and Switzerland (1:25.000 and 1:100.000) the findings from geological reports and scientific publications were integrated.
In the present model project we concentrate on 14 important geological horizons and all relevant tectonic structures.

The geological horizons are:
- base of unconsolidated rock
- base of Meletta beds
- base of Foraminifera marls
- base of Tertiary
- base of St. Ursanne Fm. (Rauracien)
- top of Hauptrogenstein Fm.
- base of the Middle Jura (Dogger)
- base of Lower Jura (Lias)
- base of Keuper (Lettenkohle)
- top of Muschelkalk evaporites (anhydrite group)
- base Muschelkalk
- base Trias
- base upper Perm (Late Permian Sandstones)
- top crystalline basement

Such a comprehensive 3D model requires a clear and up to date data management. Therefore, we handle a concept of three steps. 1) the data was stored manually within the archive of the Cantons (well data and reports), 2) borehole data including the depth of horizons is stored in a database, 3) the borehole metadata, maps and the modeled surfaces were stored within GIS-projects. These GIS-projects are directly connected with the borehole database, thus new data are incorporated immediately.
We plan to classify the influence of new data on already modeled surfaces.

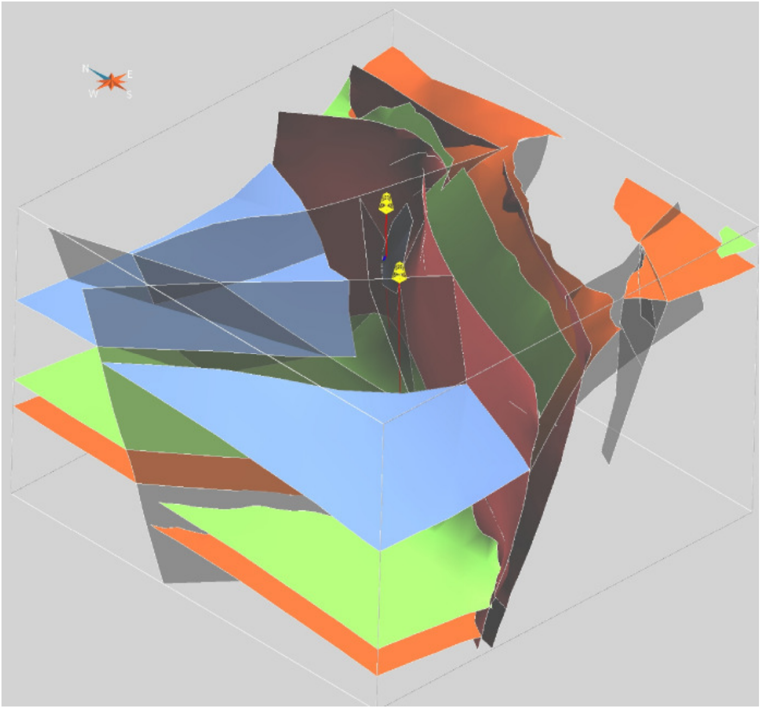

Fig. 1: Detail from the geological 3D model of the Basel region within the area of Riehen. (size: 4 x 4 km, depth ~ 2km).

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Quantitative microzonation map:
- http://www.geo.bs.ch/erdbebenmikrozonierung
- http://www.geo.bl.ch/

Three-Dimensional Analysis of the Heidelberg Basin, Upper Rhine Graben

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The Heidelberg Basin (HB) is a part of the Upper Rhine Graben that has undergone very strong subsidence throughout its existence. We present results of three-dimensional structural modeling of the basin, based on interpretation of reflection seismics, and decompaction based on our own porosity data measured from core material.
Firstly, we mapped six horizons from all available industrial (ca. 100 km) and our own reflection seismic sections (ca. 15 km), which lie within a 8 km radius around the Heidelberg UniNord 1/2 boreholes. These horizons are: Base Quaternary, Internal and Base Pliocene, Base Upper Miocene, Internal and Base Mid Miocene Hydrobien beds. This data was used to construct a three-dimensional geometrical model of the Heidelberg Basin using GoCAD (see Fig. 1). The model shows that the local HB has an N–S and E–W areal extent of only 10 x 6 km, directly abutting the eastern boundary fault of the Upper Rhine Graben. The strongest synsedimentary tectonic subsidence occurred during the Upper Miocene, Upper Pliocene, and Quaternary. Faults are not seen within the basin itself at this level.

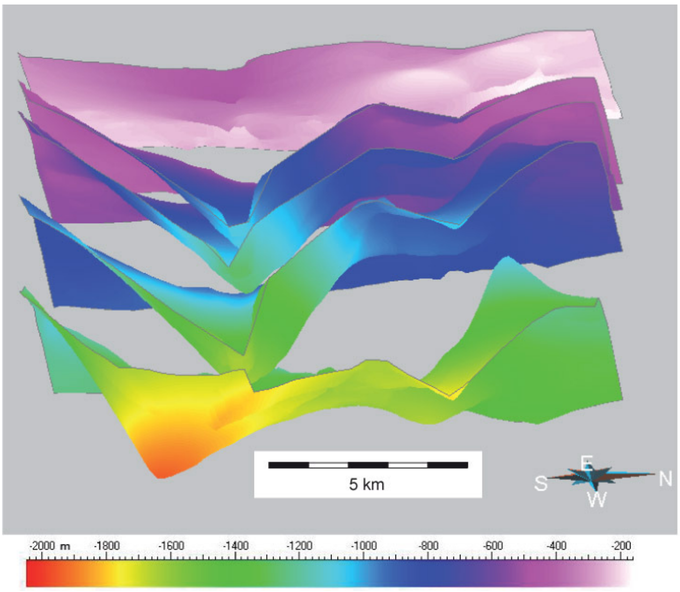

Fig. 1: GOCAD Model of the Heidelberg Basin, as viewed from the east. Surfaces colour-coded by depth, see text for names. 10x vertical exaggeration. Note the movement of the depocentres towards the north over time.

Using 300 core samples, we determined the porosity of the Quaternary sediments from their dry, saturated and submerged masses. We constructed an exponential porosity/depth relationship for these rocks, which was then attributed to the model. The model was then decompacted and backstripped in 3D. The results show that the basin was under continuous subsidence, with a slightly less subsidence rate during the Upper Miocene, but with higher rates in the Pliocene to present-day, thus the basin subsidence in general is accelerating. At the depocentre of the basin, the slowest rate of subsidence was 0.1 mm a-1, while during the Quaternary this increased to 0.2 mm a-1. The values for the Rhine Graben outside of the HB are ca. 30-50% less.

Local geological 3D models, two examples in the Rhine Graben : the geothermal potential of the Strasbourg-Obernai area and the deep geothermal site of Soultz-sous-Forêts

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The present paper describes two 3D geological models into the Rhine Graben. The first model is located between Strasbourg and Obernai, in the central part of the graben (Fig. 1). The second model included the EGS (Enhanced Geothermal System) geothermal site of Soultz-sous-Forêts in the north of the French part of the Rhine Graben (Fig. 1).

The objective of the Strasbourg-Obernai model is to assess the geothermal potential of the Buntsandstein (lower Trias) sandstone reservoir. To do this computation, we need the volume of the reservoir layer. The building of a 3D geological model of this layer is a good method to estimate the reservoir geometry.

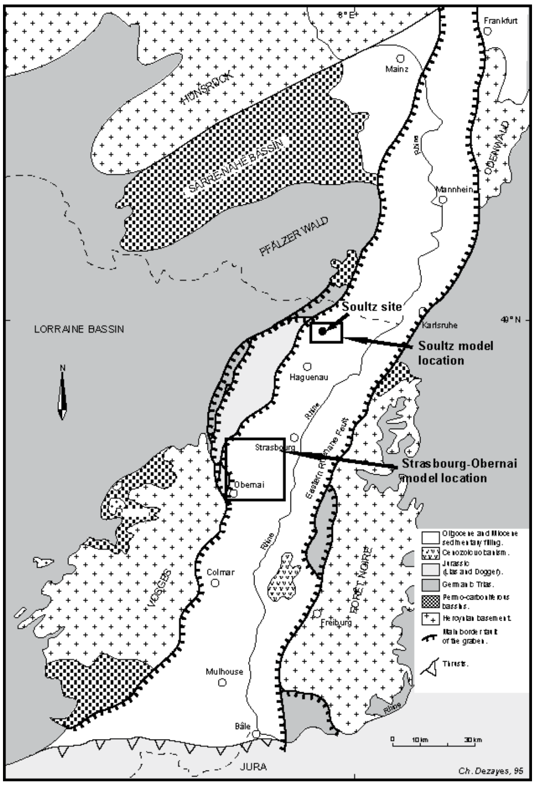

Fig. 1: Simplified geological map of the Rhine Graben with the location of the 3D geological models.

The EGS Soultz project aims to evaluate and exploit the heat potential of the deep fractured granite basement of the Upper Rhine Graben. We built a 3D geological model of the Soultz area to enhance the geometry of the faults network. This is a key to understand the fluid circulation and to improve the geothermal exploration of the Soultz area.

The building of the 3D models is based on two main kinds of data: (1) seismic profile interpretations and (2) borehole data. The seismic profiles have been acquired for oil exploration in the 70-80’s and reprocessed in the framework of the different project like GeORG (BECCALETTO et al., this workshop), for geothermal exploration of the Roquette project, or the assessment of the geothermal potential of the clastic reservoir of the Buntsandstein (CLASTIQ, a ADEME-BRGM project).

To build the 3D models, we used the Geomodeller software developed by BRGM, which is a geometric modeling software using the method of the potential field to interpolate the data (LAJAUNIE et al., 1997). To compute a model, the software uses points, orientations and a geological pile, which define the a priori geological knowledge about chronology and relation between the geological formations.

To model the fault network, we digitalized trace of faults in each cross-section corresponding to the seismic profiles. Each trace of fault has linked from section to section mainly in relation to their dip and throw. A fault can stop on others or can be secant. To establish associations between these tectonic structures, Geomodeller uses a tool that links faults to faults. The modeling allows to display the fault traces on all sections and in 3D. If the correlation is inconsistent, it is possible to modify the interpretation in varying the different parameters such as orientation data, relationship, etc…

The Strasbourg-Obernai model shows a fault network with NNE-SSW striking orientation (Fig. 2). In the southern part of the model, the basement is at around 2000m depth, whereas in the northern part, the basement ranges between 3400m and 4000m depth.
A huge fault crosses the model area and has a dip-slip throw higher than 1000m. This fault is associated in the SE part of the model with another huge fault with a throw of around 1000m, forming a graben structure with NE-SW striking orientation. In the deeper part of this graben, the basement is at 3800m depth (Fig. 2).

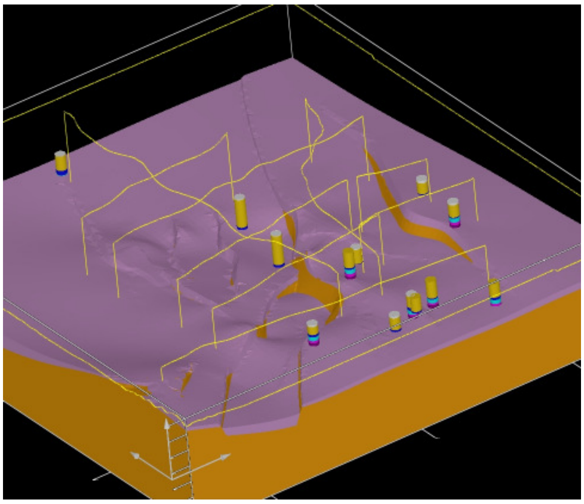

Fig. 2: View to the NE of the Strasbourg-Obernai model. Violet: Buntsandstein reservoir, orange: crystalline basement. The cylinders represent the boreholes (30 km on E-W axis and 32 km on N-S axis).

For the Soultz model, a 26 fault network could be constructed in a 30x20x6km model (Fig. 3). The orientation of the major faults is NNE-SSW (i.e. Rhenish direction) mainly dipping eastward, whereas the secondary and principally antithetic faults trend N-S to NNW-SSE, with an average dip of 60°.

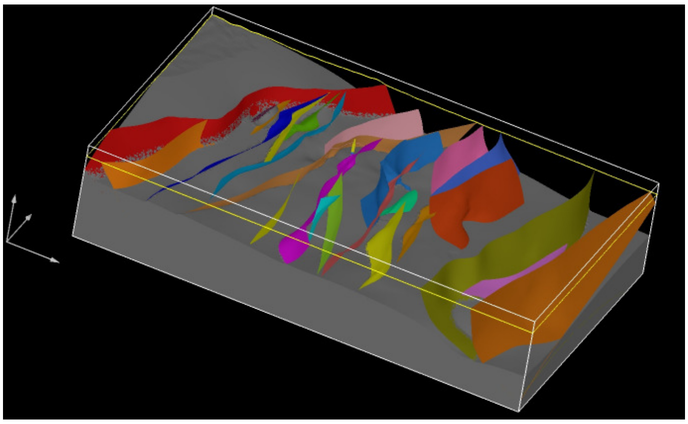

Fig. 3: View to the NW of the Soultz model. Grey: crystalline basement. The yellow cylinders represent the Soultz boreholes.

Acknowledgements

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3-D Model of Deep Geothermal Potentials in Hesse

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Introduction

In the context of a reseach project „3 D-Model of the Deep Geothermal Potential of Hesse“, financed by the Hessian Ministry of Environment, Energy, Agriculture and Consumer Protection, the deep geothermal potential for the entire federal state is quantified and qualified for direct and indirect geothermal types of use. The results are presented in maps and in three dimensional presentations.
Herewith, the decision of the Hessian Parliament (Hessischer Landtag) to describe and evaluate the potential for the use of deep geothermal energy is put into practice (FRITSCHE & KRACHT 2010). The model is intended to be a base for pilot studies and feasibility studies for concrete projects and will allow to choose areas were the economical use of deep geothermal energy can make sense. It is also intended to be an information base for the public and policy makers.

Geological Model

Fundamental data are geological cross sections from the geological maps of Hesse 1 : 25.000 and 1 : 200.000 as well as geological cross sections, seismic sections and isoline maps from literature and existing geological models of parts of the federal state. Furthermore, all borehole data archived in the HLUG and in the oil and gas data base of the Geological Surveys of Germany at LBEG were used. Concerning the latter, the data of borehole inclination were also taken into consideration.
At the Technical University Darmstadt, several computer programmes have been written to simplify the handling of the high amount of repeating working steps during the processing of the base data (ARNDT et al., 2010).
The three dimensional geological model of Hesse provides the special geometries of stratigrafic units and of selected faults and lineations (Fig. 1). Also, all existing data of the subsurface temperatures in Hesse have been integrated into the model and used to calculate their spatial distribution.
The homogeneous bodies of the geological model are attributed with temperature data and further physical rock properties. The spatial intersection of these parameters with the geometries of the geological model allows to construct the three dimensional derivation of the geothermal potential under consideration of the local stress field in Hesse, derived from the World Stress Map.

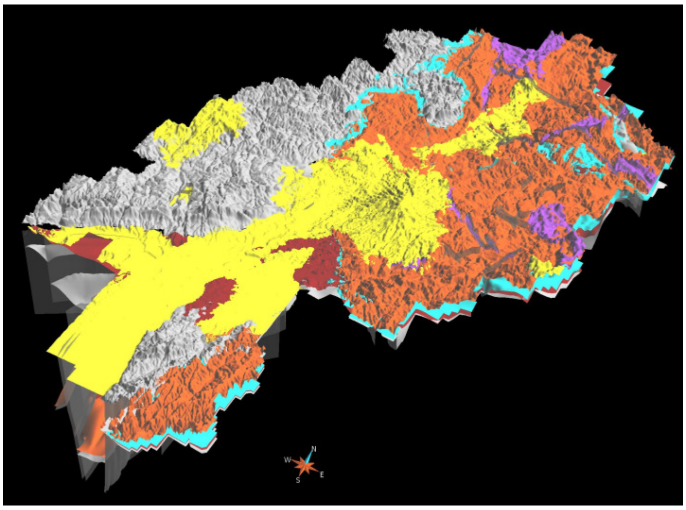

Fig. 1: Geological 3D-Model of Hesse. View from southeast with the model horizons Top Quarternary and Tertiary (yellow), Top Muschelkalk (violet), Top Bunter (Buntsandstein, orange), Top Zechstein (light blue), Top Rotliegend (red), Top Pre-Perm (grey) (ARNDT et al., 2010).

Geothermal Model

The quantifying and qualitative estimation of the potential is done for several types of geothermal use (hydrothermal, petrothermal, fault-related, deep borehole heat exchanger).
In terms of a multi-criterion approach, the several considered parameters are assessed using the respective relevance according to the GeotIS-project and included into the calculation of the potential for the several types of use.
As a base for this, for all mentioned parameters limit values have been defined to attach the particular range of values to a very high, high, medium, low or very low potential.

Grade of Permeability (DIN 18130)	Permeability [m²] /[m/s]	Transmissibility* [m³] Transmissivity* [m²/s]	Potential
Extremly high	$> 1\cdot10^{-9} / 1\cdot10^{-2}$	$> 5\cdot10^{-8} / 5\cdot10^{-1}$	Very high
Very high	$> 1\cdot10^{-11} / 1\cdot10^{-4}$	$> 5\cdot10^{-10} / 5\cdot10^{-3}$	high
medium	$> 1\cdot10^{-13} / 1\cdot10^{-6}$	$> 5\cdot10^{-12} / 5\cdot10^{-5}$	medium
low	$> 1\cdot10^{-15} / 1\cdot10^{-8}$	$> 5\cdot10^{-14} / 5\cdot10^{-7}$	low
Very low	$< 1\cdot10^{-15} / 1\cdot10^{-8}$	$< 5\cdot10^{-14} / 5\cdot10^{-7}$	Very low

* With presumed hydraulic effective thickness of 50 m

Fig.2: Limit values of distinct geothermal parameters which are used for the derivation of the geothermal potential. Every class of potential is attributed with a colour code for a simplified further presentation (BÄR et al., 2010).

The temperature in a distinct depth defines for which type of use the geological unit in the correspondent depth could be used. Beginning with a formation temperature of 60 °C, the production of thermal heat and from 100°C (technical limit) resp. 120°C (economical limit) geothermal power plants are possible. Another important factor are the hydraulic reservoir properties. Not till permeabilities resp. hydraulic conductivities which are shown as medium potential in Fig. 2 are reached, a hydrothermal use without additional stimulation measures is possible under the condition of a sufficient thickness of the formation. In this way, for the Rotliegend in the northern Upper Rhine Graben a medium to high potential for the hydrothermal electric power production can be derived because of its formation temperature and the hydraulic and thermo-physical rock properties, under consideration of the system of faults and fissures to be expected (SASS et al., 2010). In the geological/geothermal cross section in Fig. 3, the isothermal lines have been fitted interpretatively, as potential zones of hot water rising, like faults, are not yet incorporated into the temperature model. With the help of the depth of the isothermal lines and the geothermal properties of the several units know from various analyses the deep geothermal potential can be defined according to the estimation scheme presented. In Fig 3 the hydrothermal potential in the Northern Upper Rhine Graben is shown as an example. This picture also shows that the Rotliegend can be considered as a formation with medium to good conditions for the production of geothermal electric power.

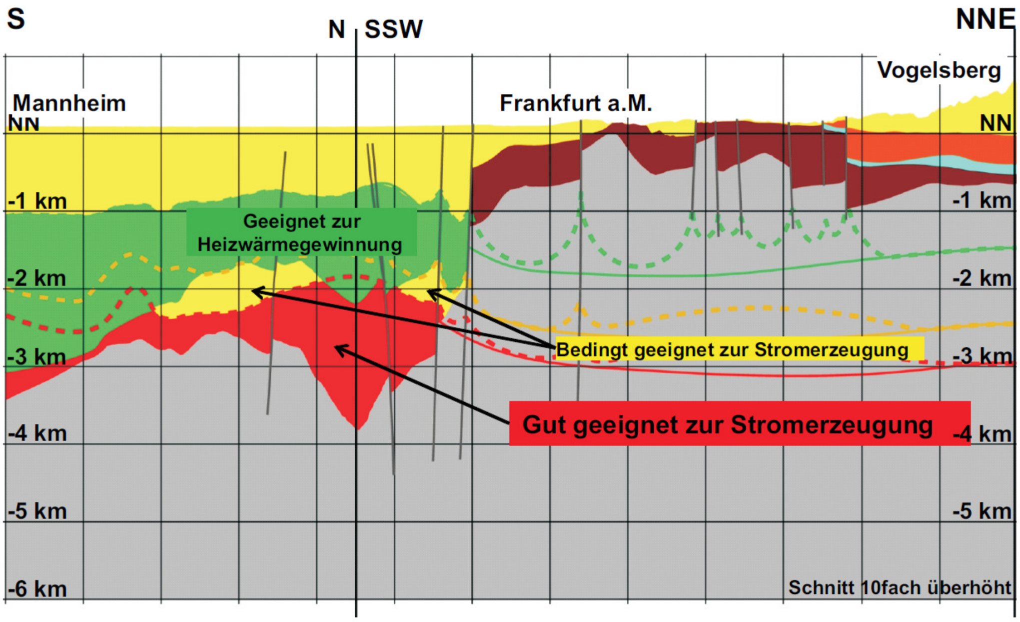

Fig. 3: Estimation of the deep geothermal potential for the hydrothermal use, from Mannheim to the Vogelsberg, with selected isothermal lines provided in the temperature model (continuous lines) and their interpretative fitting to geology and the fault system (dotted lines) (SASS et al, 2010).

Look-out

Until the finishing of the project in the end of June 2011, a three-dimensional qualitative and quantitative characterization of the deep geothermal potential in Hesse up to a depth of 6 km will exist. The publication of this work is intended to be accessible to the public as a map viewer, with a 3-D viewing programme (z.B. Adobe Reader, Geocando) and as a web-map service.

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Geothermal Reservoir Characterization and Modeling: Methods and strategies to derive thermal properties from well data and to improve model input parameter

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Models for risk minimization

Numerical simulations are well known as important tools for exploration of geothermal reservoirs, since they can predict thermal and hydraulic reservoir conditions and are able to simulate the development of a reservoir while production. However, reliable forecasts are only possible, if the subsurface geology of the area is known and the corresponding thermal and hydraulic properties are well defined. Therefore, as much as possible information should be compiled, in order to build up a geothermal model (Fig. 1). Usually data from geophysical field campaigns, geological investigation and information from existing wells in the area and the surrounding are used. The numerical geothermal model is based on a geological model, which provides the structures and geometries of the subsurface. If the model input-data are reliable and a careful model calibration has been performed, numerical simulation tool can predict the current steady state conditions as well as their development in time. These prospects are the basis for the planning and operation stages of a geothermal project. New information, gathered during the life-time of a project, can get implemented in order to improve the model step by step und such help to optimize the accuracy of forecast.

The strategies and methods, how to build up a geothermal model successfully, will be explained by the geothermal project "Den Haag". The city of Den Haag plans to provide in near future geothermal heat for about 6000 housings. The heat will be produced by a geothermal doublet, targeted to a sandstone reservoir at a depth of ~ 2500 m. In order to improve the temperature prediction for the target horizon, geothermal models were ordered in the planning stage.

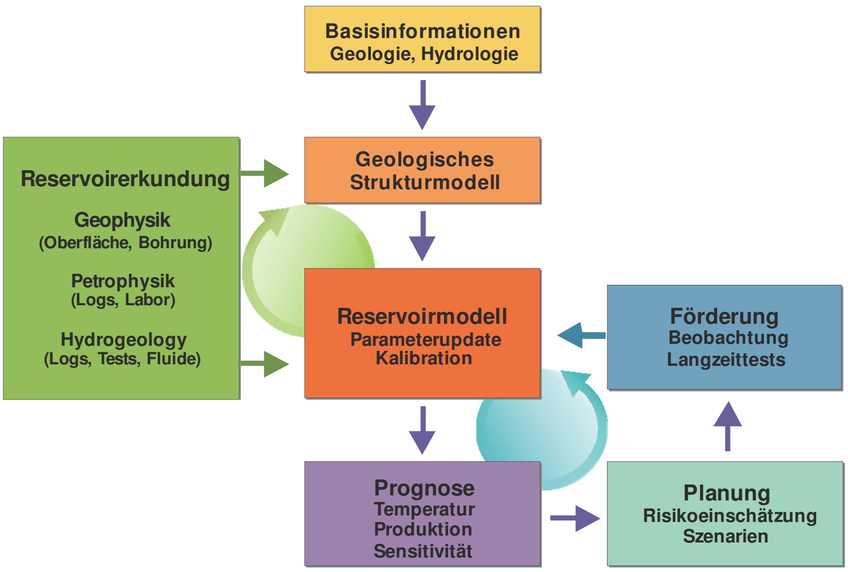

Fig. 1: Flow chart visualizing the built-up of a geothermal model and the iterative model improvement during the project life time.

Thermal characterization of the model units

Reliable temperature predictions require a large amount of parameters. Heat flow density, effective thermal conductivity and radiogenic heat production of the different layer are of major importance. During several research and commercial projects, we developed methods to extract representative data sets from existing wells. Interpretation of downhole measurements, combined with laboratory work on cores and cuttings, allow the definition of statistically proven model input parameter for all geological units considered in the model. The proceeding is explained exemplary for one key well of the Den Haag project. In order to gain direct information on the thermal properties of the rocks, samples were taken in key wells from each stratigraphic layer down to a depth of 5 km. Since almost no cores are available from the wells, cuttings material was sampled and measured for thermal conductivity and matrix density in the laboratory. In parallel, well logging data from a total of 11 existing oil and gas wells were analyzed for volumetric rock composition and porosity. Combined and calibrated with the cuttings data, the log data predictions in turn were used to calculate continuous profiles of thermal conductivity for the different wells (Fig. 2). In addition, radiogenic heat production profiles were derived from the gamma ray logs. The thermal property profiles serve two purposes: a) better description of the variability of the thermal property in a statistical manner and b) improved assessment of the spatial variation of properties within one stratigraphic layer.

Build up of numerical 3-D models

Based on the geological structure model, which was provided by TNO -Netherlands, a large scale 3-D geothermal model (22.5 * 24.3 * 5 km) and a smaller scaled reservoir model for the target horizon were constructed. Simulations were performed with the 3-D Finite Differences Code (FD) SHEMAT (Simulator for Heat and Mass Transport, Clauser, 2003).

The objective of the large scale model is to predict the current temperature conditions and to serve as frame for the reservoir model. The model consist of a total of 9 model units, each one corresponds to a major stratigraphic unit. Input parameter, which have been derived from cuttings and log analyses, were then applied to the model units. Figure 3 shows the calculated temperature distribution of the large scale model. Temperature predictions have been controlled by BTH data. The total of 10 corrected BHT data have been in good agreement with the calculated temperature values. The simulation results reveal the strong influence of the geometry and layering of the subsurface. Tectonic elements such as synclines and anticlines can affect the local temperature gradients, which can lead to significant temperature variations within one depth layer. This is shown exemplary for a horizontal cross section at a depth of 2300 m (Fig. 4). Lateral temperature variation in this depth is up to 10 K within the model area. This important model result was used to fix the target point for the production well and to optimize the drilling pathway in economical terms.

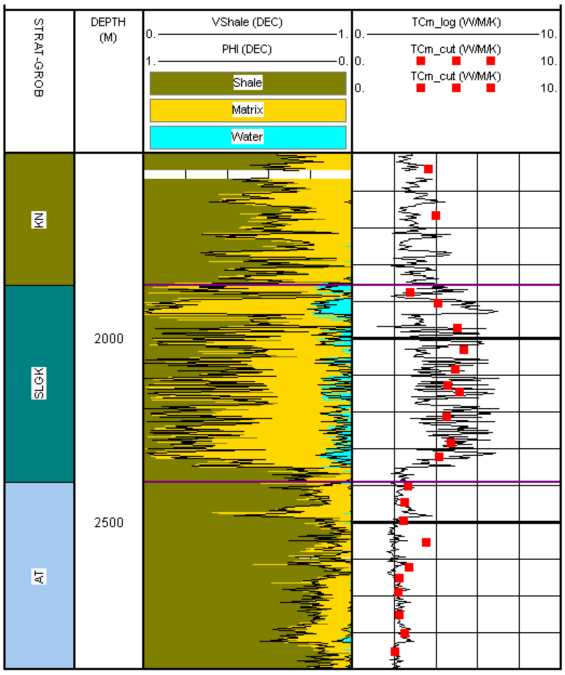

Fig. 2: The right track shows a comparison of thermal conductivity measured on cuttings with the log derived prediction (depth section: 1500-2900 m).

In a second project stage a detailed reservoir model was implemented in the large-scale model. The objective of the reservoir model is the prediction of the temperature while production and injection over several decades. The boundary conditions of the reservoir model are provided by the regional temperature model. Reservoir simulations were performed using varying hydraulic parameters for the reservoir sandstone horizon. The results confirmed the implemented geothermal doublet design as sustainable, since the aspired production temperatures are calculated to be constant over more than 50 years of production.

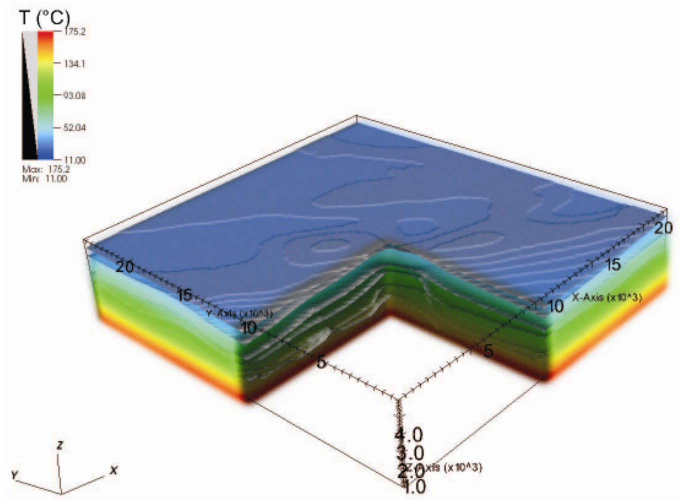

Fig. 3: Diagram of the large scale geothermal model. Temperatures are calculated down to 5 km depth.

Summary and outlook

The case study shows that a careful data handling and analyses will lead to representative input-values for numerical geothermal models. The combination of log data analyses and laboratory measurements on core and/or cuttings has been proved as a very reasonable approach. The applied log–cuttings integration produces significant values for entire stratigraphic succession of a target area. Beside the case study presented, this method was successfully applied also for formations of the South German Molasse Basin, the North German Basin, the Lower Rhine Basin, the Rhenish Massif and the Gippsland Basin, Australia. In a slightly modified version, the method could be adopted also to drill holes located in the South German crystalline basement (Urach, KTB).

The results of case study further show, that well defined and calibrated models are able to produce reliable forecasts on subsurface temperatures. This autumn, the first drilling of the Den Haag project has successfully reached the target horizon and confirmed the model based predicted temperatures (http://www.aardwarmtedenhaag.nl).

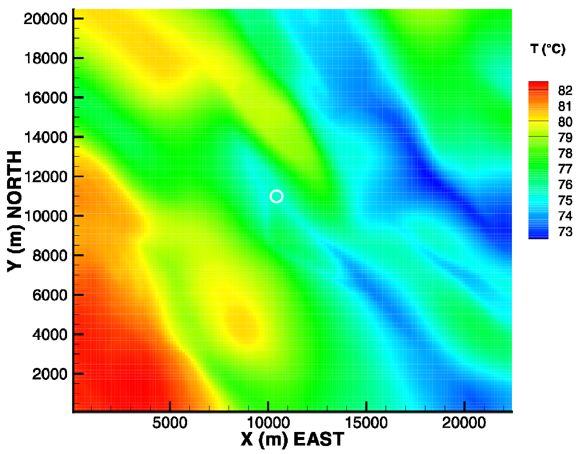

Fig. 4: Horizontal cross section of the temperature model in a depth of 2300 m. Temperature varies up to 10 K in this depth.